Exploitation of Thermal Signals in Tidal Flat Environments

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LONG-TERM GOALS

The overall goal is to identify and understand the physical processes that shape and change coastal environments. Emphasis is on the application of remotely sensed infrared signals that can be compared with in situ observations and assimilated within predictive models. In tidal flat environments, major goals are detection of: geotechnical properties (e.g., sediment strength), morphologic features (e.g., channels), and hydrodynamics events (e.g., plumes).

OBJECTIVES

The primary objective of these joint efforts is to develop thermal methods for improved monitoring and prediction of tidal flat environments. Specific objectives are to:

- Test and apply the Lovell [1985] hypothesis for the porosity of sediment as a function of thermal conductivity,
- Refine methods to estimate inter-tidal bathymetry using sequential waterline detection,
- Quantify the importance of channel networks and associated flows.

APPROACH

The technical approach is to conduct field experiments using simultaneous remote and in situ observations of thermal signals in tidal flat environments. Infrared images collected from airborne and fixed platforms are being used to study surface temperatures, which are then related to an array of interior (sediment and water) temperature measurements. The experiments are designed to study geotechnical, hydrodynamic, and morphologic aspects of tidal flats.

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The sediment temperature data is analyzed using Lovell's [1985] empirical formula for the fractional porosity n (i.e., the water content) of saturated sediments as a function of thermal conductivity k, where

$$k = k_s^{(1\text{-n})} + k_f^{(\text{n})},$$

and k_s, k_f refer to the thermal conductivities of the solid and fluid, respectively. Assuming a 1D heat balance, the temperature T at the surface of the sediment (measured using infrared imagery, see Figure 1) diffuses downward in a vertical z profile (measured using buried loggers) at a time t rate governed by

$$\mathrm{d}^2T/\mathrm{d}z^2 = (c\rho/k)\ \mathrm{d}T/\mathrm{d}t,$$

where k is the thermal conductivity of interest, c is the specific heat, and ρ is the density [*Subramaniam and Frisk*, 1992; *Jackson and Richardson*, 2002]. Sediment porosity n is estimated by finding the best-fit k at each location in the imagery and then is compared with sediment samples.

Differential sediment and water surface temperatures are used to detect waterlines and thereby estimate bathymetry. Waterlines extracted within plan-view infrared images at incremental tide stages will be interpolated to a Digital Elevation Model (DEM), similar to work with optical imagery in the nearshore [*Plant and Holman*, 1997] and infrared satellite imagery [*Ryu et al*., 2002]. Infrared imagery is well suited to shoreline identification due to the differential heating rate of sediment (fast) versus water (slow). We have increased the likelihood for quality data return and the general image resolution over satellite imagery by developing and deploying a small aircraft based thermal imaging system. Flying over the flats in a "lawn-mowing" fashion, we later georectify and mosaic the collected imagery for quantitative analysis. Bathymetry estimates will be compared against ground surveys collected during the pilot experiment.

Finally, the infrared images are used to quantify surface fluid velocities (following the method of *Chickadel et al.,* 2003), especially for flows too shallow for in situ measurements. The associated temperatures can then be used to estimate the source of the volume flux by applying conservation of heat.

WORK COMPLETED

FY11 efforts concentrated on data processing and publication, using data collected in previous years of the project. In particular, data collected in Willapa Bay during March 2009 have been processed to quantify flow within a channel during low tide and identify the source as pore water from within the mudflats. Figure 1 shows the location of these measurements and the bathymetry of the channel. These results have been submitted [*Rinehimer et al,* submitted] to a journal special issue on tidal flats. In addition to the hydrodynamic emphasis, work has continued on geotechnical and morphological topics.

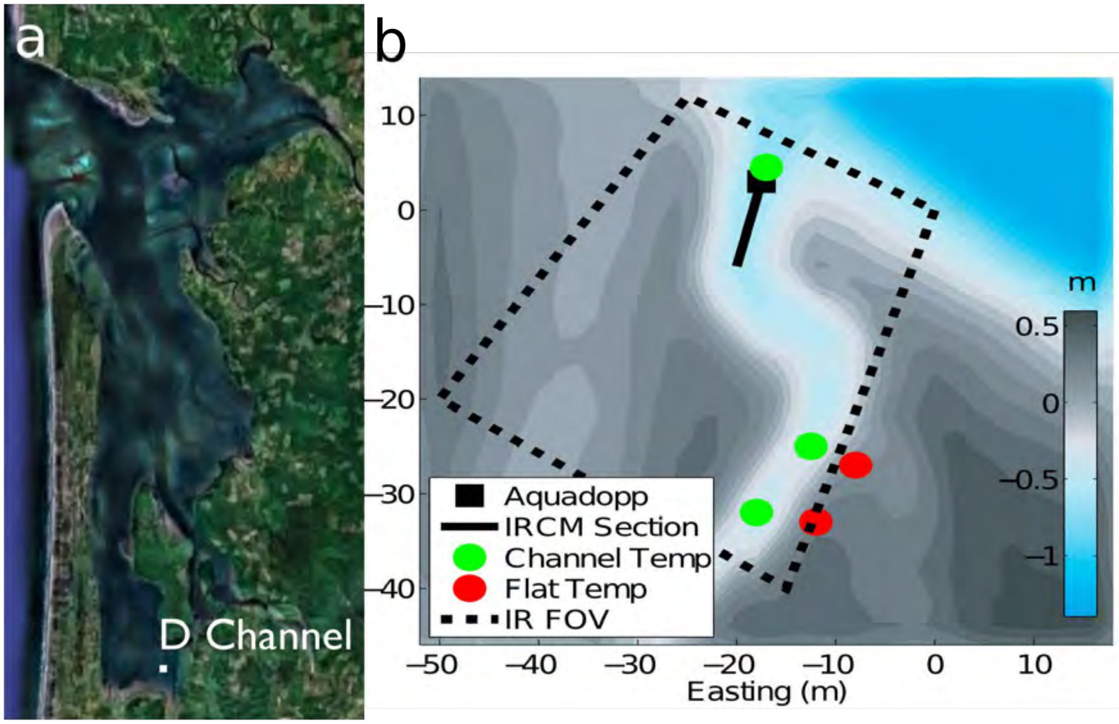

Figure 1. Willapa Bay (a) and the 'D' channel (b) where infrared, LIDAR, and in situ measurements were combined to identify the outflow of pore water from mudflats.

RESULTS

Using a combination of remote infrared imagery and in situ temperature measurements, we have quantified the flow in a tidal channel at low tide and confirmed the source as pore water from mud flats (as opposed to surface water drainage). In addition to a strong correlation of temperatures between the channel outflow and the sub-surface mud, a hydrodynamic analysis shows the low-tide outflow to be distinct from the ebb drainage, consistent with 'baseflow' observed in groundwater studies. This flow is also consistent with the classic Manning equation for open channel flow. Figure 2 shows the flow and temperature measurements applied for these results.

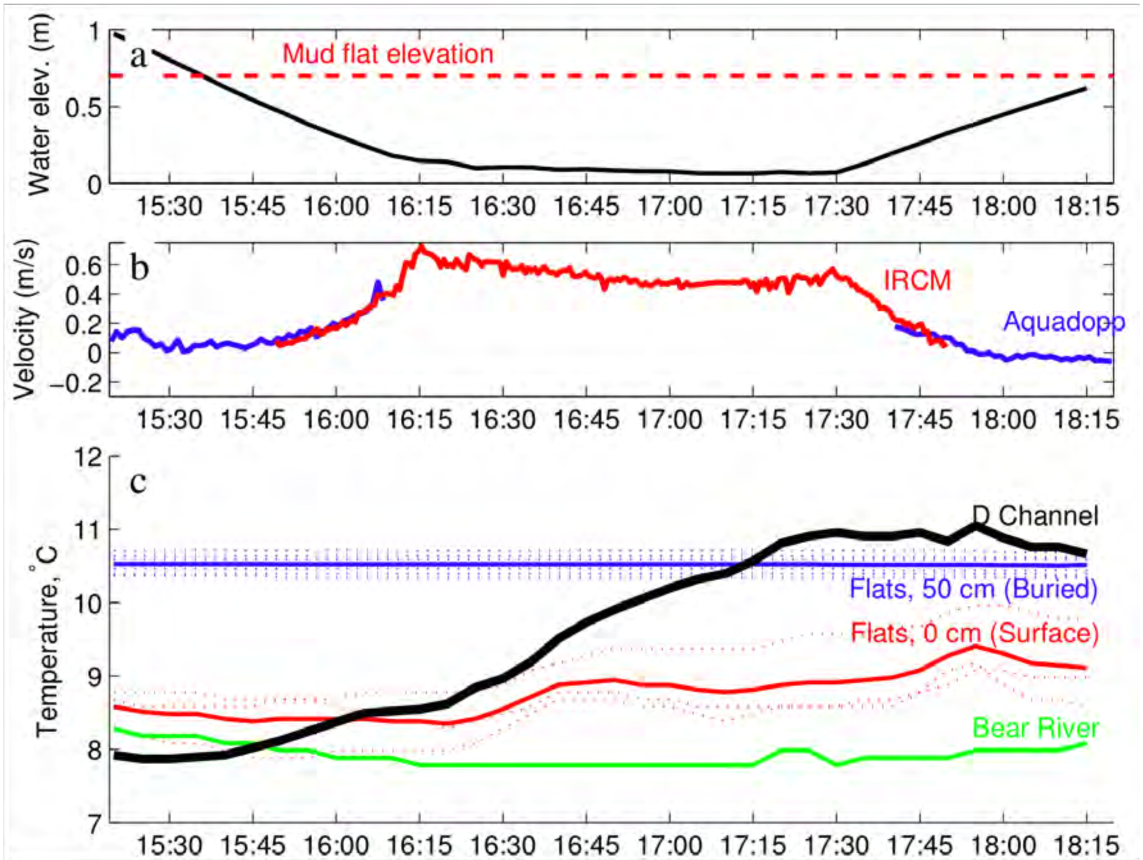

Figure 2. Tide level (a), flow velocity (b) from both in situ Aquadopps and Infrared Current Meter (IRCM), and in situ temperatures (c). The flow velocities from the different methods are in agreement, and a distinct transition is observed from drainage flow (surface water) to baseflow (pore water) at 16:15 UTC.

Results from previous years confirm that thermal signals can be used to remotely classify sediments and detect bathymetric features. In particular, the heat flux of exposed sediments is related to the composition and porosity of sediments (*Thomson*, 2010), consistent with an empirical model for thermal diffusivity as a function of porosity (*Lovell*, 1985). Sediments absorb heat during periods of strong solar radiation consistent with a 1D diffusion equation (*Kim et al.*, 2007). The sandy sediments have a much stronger response to heating, because the water content and porosity is lower, compared with the muddy sediments. These results are being assimilated into a large-scale, coupled thermodynamic-hydrodynamic model of the flats, which will be the focus of FY12 efforts.

IMPACT/APPLICATIONS

Improving techniques to remotely quantify tidal flat properties will allow for real time monitoring and safe operation in these environments. In particular, remote porosity estimation and channel detection will improve navigation for amphibious landings.

RELATED PROJECTS

A new “helikite” imaging platform, developed under a DURIP (PI: Andrew Jessup), has dramatically improved spatial coverage of our infrared sensing by providing additional elevation and dwell time.

A new DoD MURI (Data Assimilative Modeling and Remote Sensing for Littoral Application, PI: Andrew Jessup) will benefit from experience gained here and use many of the techniques and equipment tested in these sets of experiments.

This effort is a contribution to the Tidal Flats DRI (www.tidalflats.org).

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PUBLICATIONS

None.

HONORS/AWARDS/PRIZES

None.